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Workwear Fabric Suitability to Molten Metal Industry

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ABSTRACT

In the scope of the foundry processes, there are vital risks when melting of metals at high temperatures, carrying this molten metal to molds and pouring it to molds. In this study, wide range of workwear materials which are used in foundries in Turkey were collected and their protection properties were investigated to observe their performances. Determining suitable material to molten metal processing was aimed. These workwear materials were produced from FR-cotton, cotton denim, modacrylic-viscose-FR cotton, meta-aramid, aluminized aramid, FR viscose-wool-polyamide and leather. Their performances were very different. Except from meta-aramid and both of the FR cotton fabrics, other fabrics failed flame spread. Contrary to flame spread, leather, aluminized aramid, FR viscose-wool-polyamide and cotton denim materials showed the highest values in molten metal splash test. Besides, leather had no air permeability but has some water vapor permeability and aluminized aramid has poor air and water permeabilities.

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KEYWORDS

Molten metal, workwear, protective clothing, molten aluminium, foundry

1. INTRODUCTION

Metal foundry industry in Turkey is one of the most important sectors taking 3rd place in Europe and 11th place in the world having nearly 34,000 employees of this industry. Aluminium die casting is rising in area Turkey, total production 20% increased from 2017 to 2018. This is the reason of our decision to investigate aluminium protection properties of varios fabrics. Foundry process involves three main steps, heating metal until it becomes molten; pouring molten metal into a mold; and allowing the metal to cool and solidify in the shape of the mold. Correct casting temperatures are important for quality of cast product. Melting temperatures of metals are very high, i.e. 660^{o}C for Aluminium, 1536^{o}C for iron, etc. These processes endanger the life of workers; however, proper workwear can protect them. Wide range of fabrics are used in foundry workwear from cotton to special fibers like modacrylic, aramid, even leather and each of them has different performances and prices. In general, there are three types of molten metal exposures in industry: poured molten metal, welding droplets and molten metal splashes due to an electric arc. In foundry sector, poured molten metal is the main exposure for employees. In addition, foundries are very hot environments and this causes uncomfortable feelings causing loosing attention in shortterm exposure and heat stress hazards in longterm exposure. In protective product selection, temperature, density, size of droplets and the reactivity (sticking) of droplets are determining factors [1,2].

There are few works about molten metal protective textile materials, most of them rather old. Barker and Yener, worked on molten iron protection. They found iron resistance was correlated with fabric thickness, weight, air permeability and flammability properties [3]. Benisek, Edmondson and Philips aimed at measurement of protection properties of especially zirpro FR (flame retardant) wool and other protective clothing against convective and radiant heat and aluminum splashes. They developed the molten aluminum protection test method similar to recent one. They concluded that increased fabric weight and density, low thermal conductivity and smooth fabric surface were important for molten aluminium protection [4]. Benisek and Edmondson in 1981, evaluated the effects of different conductive heat sources as molten metals (cast iron, steel, copper, aluminium, zinc, lead and tin) on various FR fabrics. They indicated inherent flame

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retardant property (i.e. glass, asbestos and aramid fibers) is not sufficient for molten metal protection. Zirpro wool was find to be a good example of molten metal protection, untreated cotton showed slightly lower protection while FR treated cotton fibers worser than the others against aluminium and zinc [5]. Proctor and Thompson in 1992 focused on finished wool fibers and effects of the finish chemicals to molten metal adhesion. They found that chrome dyeing and zipro finish on wool increase adhesion of molten aluminium and zinc. This result of chrome dyeing is similar to the results from Benisek and Edmondson in 1984 [6, 7]. Coughlan worked with different fabrics against molten aluminium. It is found that damage to skin simulant was not dependent on flame retardancy but dependent on surface properties of fabrics at high temperatures and duration of molten metal-fabric contact (sticking). FR treatments on cotton causes sticking and softening of synthetic inherently flame retardant fibers occurs and causes trapping of metals are the other conclusions [8]. Magnússon et al., investigated molten aluminium protection properties of FR cotton, FRviscose/wool/cotton, viscoseFR/PVA/modacrylic, viscose FR/wool fabrics. They concluded that to obtain D3 level protection of ISO11612, underwear usage was essential. Additionally, they examined the behavior of molten aluminium when small and big folds occur in the fabric. If there was big fold, molten aluminiun may stop and cause damage in skin simulant [9]. Mäkinen et al. studied fabric layer combinations instead of single fabrics. They found that use of FR underwear is useful to increase the level of molten iron protection [10]. Lee highlighted the number of PPE advancements in Australia. Paper explained the preferred not only clothing but all components of personal protective equipment (PPE) [11].

Surveying literature, it is seen that molten metal protection properties of various fabrics were investigated in detail [3-11]. Although performances of certain types of fabrics are known, a workwear's overall performance cannot be concluded without mechanical performances and comfort properties convenient to work conditions. In addition, there are very wide range of workwear fabrics available and in use for foundry workers in Turkey. However, due to very high temperatures, carefully selected specific materials should be used regarding protection and the other performances. That was our motivation and in this research, we investigated primarily molten aluminium and flame protection properties of various fabrics and one leather sample, together with physical-mechanical and permeability features. Leather cannot be found in literature but it is in common use for molten metal processing especially as gloves and aprons. The aim of the research was to determine properties of fabrics and leather used in workwear clothing in Turkey and to assess the better material showing suitable performance.

2. MATERIAL AND METHOD

2.1 Material

Seven types of fabrics that are mostly used in workwear of Turkey's foundry industry and one type of leather were provided. Firstly, fabric structures, area weight (TS 251), thickness (TS 7128 EN ISO 5084 - 5 g/cm^2 pressure), warp and weft yarn numbers, fabric settings and tensile strength (TS EN ISO 13934-1 for fabrics and TS EN ISO 3376 for leather) properties were determined. The results are given in Table 1.

Table 1. Physical properties of fabrics and leather

Code	Samples	Weave Type	Area weight (g/m^2)	Fabric Thickness (mm)	Weft count (thread/cm)	Warp count (thread/cm)	Weft yarn number	Warp yarn number	Tensile Strength (N)
101	Meta-aramid	Plain weave	248.61	**0.642**	30	19	Nm 17	Nm 12	1565.8
102	Modacrylic-Viscose-FR cotton	twill (2/2)	249.23	**0.474**	33	30	Nm 22	Nm 30	603.7
103	Cotton 1- FR1 (Apyrol CEP-CHT)	twill (1/3)	565.21	**1.110**	17	30	Nm 14	Nm 12	1026.5
104	Leather	-	735.35	**1.042**	-	-	-	-	308.5
105	Cotton 2- FR2 (Proban-Solvay)	twill (1/5)	331.06	**0.708**	30	41	Nm 14	Nm 22	1194.5
106	Aluminized aramid	-	273.52	**0.736**	-	-	-	-	884.0
107	Cotton 3-Denim	twill (2/2)	431.42	**0.780**	24	32	Nm 17	Nm 12	1387.4
108	FRViscose-Wool-Polyamide	Plain weave	420.68	**0.770**	30	30	Nm 17	Nm 17	592.4

2.2 Method

Flame retardancy, molten metal protection, pH values, fat content of the leather, abrasion strength, resistance to water penetration, air and water vapor permeability features of the materials were examined.

ISO 15025 standard - procedure A was used for limited flame spread test. pH values that are important when materials contacts to skin were measured according to TS 477 EN 1413 for fabrics and TS EN ISO 4045 for leather. Fat content of the leather was found according to TS EN ISO 4048. In foundries, wearing out of clothing by mechanical effects are occurred, therefore, TS EN ISO 12947-1 was used to obtain abrasion resistance. 30000 cycles were applied to samples and after every 5000 cycles weight losses were calculated. Additionally, resistance to water penetration (TS 257 EN 20811), air (TS 391 EN ISO 9237) and water vapor permeability (BS 3424-24) tests were applied to observe permeability properties.

Molten metal protection was measured according to TS EN ISO 9185 standard with home-made device (Figure 1(a)). Aluminium (99.5%) was used as metal. In this test method, certain amount of molten metal starting from 50grams is poured at a certain speed onto fabrics that are placed on 60º inclined apparatus. Under fabric sample, a specific PVC film as skin simulant is used. At the end, 30s after completion of pouring, damage to skin simulant (not to fabric) is examined. The damage means 5mm in width or bigger stain on skin simulator as seen in Figure 1(b). If there is no damage, test is repeated with new specimen using a quantity 50g greater molten metal than the amount of previous test. If there is damage, test is repeated with new specimen using a quantity 10g less than the amount of previous test. The result is the highest mass of metal poured that does not caused damage. So fabrics are ranked by the quantity of molten aluminium that they can protect skin in heat and flame protective workwear standard, ISO 11612. Molten alumnium protective fabrics or assemblies should meet the criteria at least level D1 (100g-199g) as protection from minimum 100g of molten aluminium. (D2: 200g-349g; D3: equal or higher than 350g) Aluminium pouring temperature is 780ºC [2].

3. RESULTS AND DISCUSSION

3.1 Tensile and Abrasion Strength of Samples

Workwear fabrics must show protective properties against hazards in the workplaces, however, without durability of fabrics, protective excellence loose importance. In order to determine better material, breaking strength and elongation values of fabric samples were measured and shown in Table 2.

(a) (b)

Figure 1. **(a)** Molten metal protection measurement device, **(b)** Damaged fabric and skin simulator with damage bigger than 5mm in width (101-aramid fabric with 10g of molten aluminium)

Table 2. Tensile strength and elongation at break values of the samples

Fabric Code	Tensile Strength-Weft direction (N)	Tensile Strength-Warp direction (N)	Average Tensile Strength (N)	Weft-elongation	Warp-elongation	Average Elongation
101	1602,5	1529,0	1565,8	%45,7	% 24,3	% 35,0
102	619,5	587,8	603,7	%19,4	%26,9	% 23,2
103	889,2	1163,8	1026,5	% 8,1	% 19,7	% 13,9
104	-	-	308,5	-	-	% 49,1
105	1713,0	676,0	1194,5	%12,3	%13,9	% 13,1
107	909,7	1865,1	1387,4	%13,0	%27,2	% 17,2
108	658,2	526,6	592,4	%21,4	%30,5	% 28,9
	Course direction	**Wale direction**		**Course direction**	**Wale direction**	
106	844.8	923.9	884,0	%78,2	%19,0	% 48,6

When look through the table, there are remarkable differences in the values. The reasons seem to be the types of weave and the fibers. Because meta-aramid fiber strength is inherently high. Cotton fabrics whose weave types were twill showed high strength values. Additionally, fiber strengths of cotton, wool, modacrylic and polyamide fibers are 0.45 N/tex, 0.11 N/tex, 0.27 N/tex and 0.29 N/tex, respectively. Course direction elongation of aluminized aramid was extremely high. This coated product was in warp knitted structure and the elongation extend can be seen in Figure 2. Three twill cotton fabrics have the lowest degrees of elongation because cotton fibers have lower elongation at break values than the other fibers [12-15].

Figure 2. Elongation of aluminized aramid fabric

The same protective workwear piece may show different properties in different factories depending on product of the foundry, processing units, production conditions, etc. Abrasion resistance of fabrics is affected by fiber type, yarn properties, fabric structures and finishing treatmens [13]. The results are seen in Figure 3.

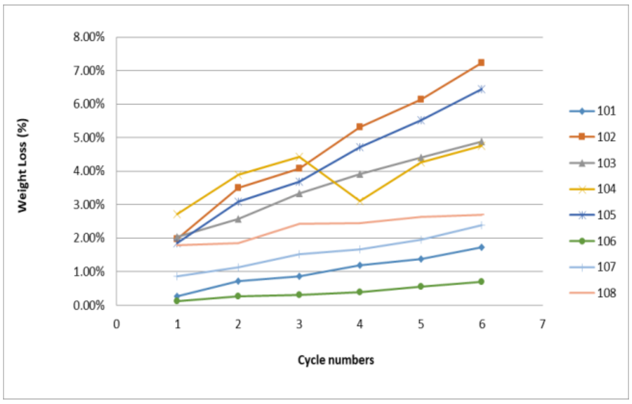

Figure 3. Abrasion strength of materials (cycle numbers x 5000)

The best result was obtained from aluminized aramid sample. It may be due to metalic coating on the fabric gave it protection layer against abrasion. Meta-aramid fabric and cotton denim fabric samples are following aluminized aramid. Modacrylic-viscose-FR cotton blended fabric was the worst sample in abrasion test. Thickness may be the reason hence this fabric is the thinnest fabric sample [13,16].

3.3 pH Value and Fat Content of the Leather

The results of pH value measurements and fat content of leather is seen in Table 3.

Table 3. pH values of the samples and fat content of the leather

Fabrics		pH values
101 - meta-aramid		6.66
102 - Modacrylic-Viscose-FR cotton		6.65
103 - Cotton 1- FR1		7.26
104 - Leather	Mean Fat Content: 0.862 %	3.75
105 - Cotton 2- FR 2		8.72
106 - Aluminized aramid		6.45
107 - Cotton 3 – Denim		7.65
108 - FRViscose-Wool-Polyamide		7.86

Because these workwear fabrics are in direct contact with skin, their pH value must be harmless to skin of the wearer. For innocouousness, pH should be close to neutral pH (pH 7). Except leather, all test samples seem to have compatible pH degree with human skin. Fat content of leather materials should be below 15% according to TS EN ISO 11612. Therefore, the leather sample of this study is suitable for this criteria.

3.3 Limited Flame Spread

The criteria when applying this test are not quantitative. Requirements of TS EN ISO 11612 are no specimen shall permit any part of the lowest boundary of any flame to reach the upper or either vertical edge; no specimen shall give flaming or molten debris; no specimen shall give hole formation of 5 mm or greater in any direction, except for an interlining that is used for specific protection other than heat and flame protection; afterglow time shall be ≤2 s and afterflame time shall be ≤2 s. If all criteria are fulfilled, this means that the sample passes the test. The results of this test is given in Table 4.

Table 4. Results of limited flame spread test

Fabric type	*Fabric Thickness (mm)*	*Vertical Flame Spread Test- (Pass / Fail)*
Meta-aramid	0,642	Pass
Modacrylic-Viscose-FR cotton	0,474	Fail
Cotton 1- FR1	1,110	Pass
Leather	1,042	Pass
Cotton 2- FR 2	0,708	Pass
Aluminized aramid	0,736	Fail
Cotton Denim 3	0,780	Fail
FRViscose-Wool-Polyamide	0,770	Fail

In this test, inherently flame retardant meta-aramid fabric, flame retardant treated cotton fabrics and leather passed the criteria as expected. The other fabrics showed worse results because their 'afterflame time' exceeded limits, even aluminized fabric. Aluminized fabrics are produced mainly for heat reflectance. Besides, because its high thermal conductivity causes other types of heat transfer easily to fabrics lowering protection properties. Additionally, aluminium can melt under the flame condition, due to flame temperature of propane is higher than its melting burning point as approximately 660ºC (in our device we measured flame temperature approximately 720ºC) [17-19].

3.4 Molten Aluminium Protection Test

Starting amount of molten aluminium was 50g. Evaluation criteria for the test is any damage in the size of 5mm in width on PVC skin simulator. The results are given in Table 5.

As seen from the table, protection degrees of the samples are in two extreme group. One half of the fabrics are maximum protective against molten aluminium but the other half is absolutely inadequate to use in this field even they have flame retardant properties. We can conclude that flame retardant property does not refer to molten aluminium protective property, similar to literature [5]. In Figure 4, pictures of results of protective fabrics are shown. Aluminized fabric is also protective and image of samples tested with different molten aluminium weights are given in Figure 5. Result from fabric sample 101-meta-aramid was given in Figure 1.(b).

Table 5. Molten aluminium protection test results

Fabrics	Amount of poured molten aluminium that does not damage PVC skin (g)	Weighed amount of aluminium (g)
101 - Meta-aramid	<7.04 g	10
102 - Modacrylic-Viscose-FR cotton	<6.33 g	10
103 - Cotton 1- FR1	26.69 g	30
104 - Leather	>334.00 g	350
105 - Cotton 2- FR 2	<8.99 g	10
106 - Aluminized aramid	>343.83 g	350
107 – Cotton 3 - Denim	>345.54 g	350
108 - FRViscose-Wool-Polyamide	>346.66 g	350

Figure 4. 350g - molten aluminium tested samples and related PVC skin simulant (from left to right: LenzingFR-Wool-Polyamide, Cotton 3-Denim, leather)

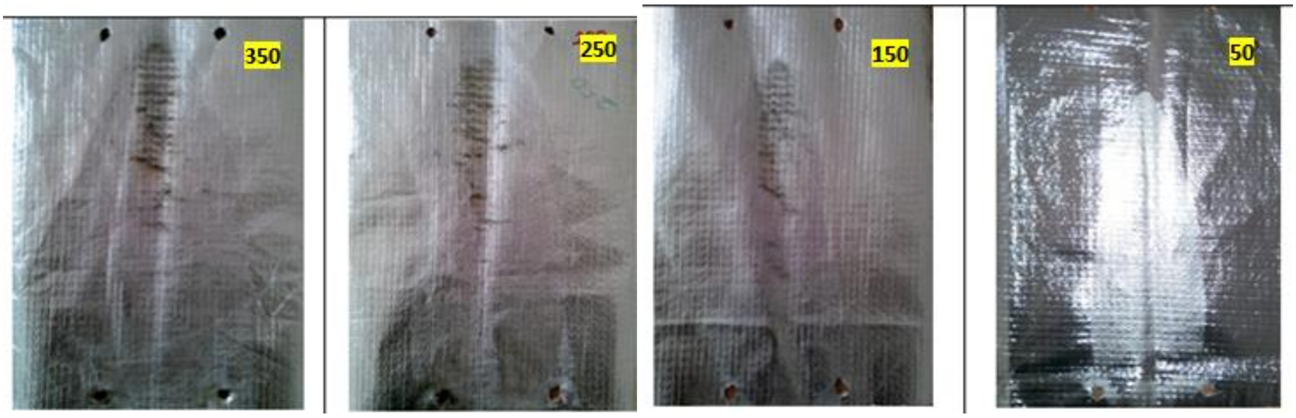

Figure 5. Aluminized aramid fabric tested with different amounts of molten aluminium

As seen from the Figure 1(a), meta-aramid fabrics showed a sticky surface for aluminium metal, therefore, damage to PVC skin was severe. The reason is softening of meta-aramid fibers when a molten metal poured on. Figure 4 shows the views of 350g weigthed aluminium poured materials (leather, denim and LenzingFR-wool-polyamide) and PVC skins. As seen in the picture, none of the fabrics shrinked and was damaged, PVC film was not damaged, too. Figure 5 shows the change on the surface of aluminized aramid fabric. Altough surface was changed by increasing amount of molten aluminium, PVC skin was not damaged.

3.5 Water, Watervapor and Air Permeability Tests

In addition to protection, permeability properties must be taken into account because using the protective clothing at work require comfort and ability to work with these clothes (Table 6).

Air and water vapor permeability properties are related to comfort feeling of a textile structure. Feeling comfortable is important to be able to do work properly in any work field. From the table, air permeability values of leather and aluminized fabric seem to feel workers uncomfortable because they are not breathable. Aluminized fabric has a water vapor permeability value lowest among others, however, leather has some watervapor permeability to permit watervapor to pass through. Except from aluminized aramid, none of the fabrics have water resistancy. In fact foundry work does not need water resistancy, if the work is realized in outdoor condition.

4. CONCLUSION

All these fabric samples were available for molten metal industry in Turkey, even from expert suppliers or from conventional workwear fabric sellers. Wide range of physical and performance properties were obtained from the tested eight different materials. Besides having good protective performances, some samples showed poor comfort related properties. Except from leather, meta-aramid and two FR cotton fabrics, other fabrics were failed from flame spread test because same specimens continued burning. Contrary to results of the flame spread test, leather, aluminized aramid, FR viscose-wool-polyamide and cotton denim materials show the highest values in molten metal protection test. Regarding flame spread test and molten metal protection, only leather sample showed good results for both tests. However, leather has some water vapor permeability but has no air permeability. This means protection good but comfort of the wearer cannot be obtained. For this reason, as a result, novel protective fabrics may be investigated to be used in our country for molten metal protection. Besides, as an alternative, in the production of protective clothing for foundry workers, a clothing design approach combining different materials in one clothing in order to obtain protection, comfort, and affordability at the same time should be regarded for engineered manufacturing.

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Table 6. Air and water vapor permeability and water resistance results

Fabrics	Air permeability (l/m^2s)	Water vapor permeability index (%)	Water resistance (cm-water column)
101 - Meta-aramid	80.56	103.29	20.7
102 - Modacrylic-Viscose-FR cotton	81.80	95.07	23.4
103 - Cotton 1- FR1	89.96	94.37	23.7
104 - Leather	0.00	79.41	53.1
105 - Cotton 2- FR 2	160.20	129.52	N/A
106 - Aluminized aramid	4.29	7.62	310.0
107 - Cotton 3 - Denim	52.92	110.80	13.8
108 - FRViscose-Wool-Polyamide	77.34	94.76	N/A

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